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A STUDY OF HEART SOUND, GALVANIC SKIN RESPONSE, AND BLOOD PRESSURE IN THE MEASUREMENT OF HUMAN ENERGY EXPENDITURE

A THESIS

Presented to

the Faculty of the Graduate Division

by

Charles Jay Schwartz

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Industrial Engineering

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Approved:

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SUMMARY

A problem of long standing in industrial engineering has been that of finding an operational method, which would be applicable to the industrial work situation, of quantitatively determining physical exertion. The purpose of this study was to investigate this area of research and to add significant information which could eventually be a valuable aid to industrial engineering.

The procedure involved experimental human engineering. Five male college students were randomly selected from a group of sixty students to perform a work task on a torsion bar machine which required an energy expenditure easily calculated by mechanics. The subjects performed the task at two different speeds two times at each speed. During each work period, the subject worked for three minutes and rested for three minutes five times. At the end of each work period of three minutes, recordings were taken of heart sound, galvanic skin response, and blood pressure. These readings were subjected to an analysis of variance in an effort to determine the effects on these measurable variables, of the different subjects, length of time the subjects performed the tasks, the replications of the tasks, and the two speeds at which the subjects performed the tasks.

The results showed that under the conditions of this experiment, replication, speed, and the speed and operator interaction showed no statistical significance. Differences among operators, however, did cause a significant difference in the readings of both systolic and

diastolic blood pressures. Also, the time period lengths significantly affected the galvanic skin response, heart sound, and difference between systolic and diastolic blood pressure readings. The speed and time periods interaction was significant in affecting heart sound while the interaction between operators and time periods was a significant influence on the diastolic blood pressure readings as well as those of heart sound.

These results were encouraging in that, even though the work was too light, due to the speed at which the subjects worked, to affect the readings, the length of the time periods affected the heart sound, GSR, and the difference between systolic and diastolic blood pressures. It is recommended that future study incorporate experiments covering longer periods of time and involving more strenuous tasks in order to determine if these variables will continue to indicate the energy exerted by the subjects and eventually by workers in an actual work situation.

NOTATIONS AND ABBREVIATIONS

L = Speed = i = 1,2

T = Time Periods = j = 1,2,3,4,5,6

R = Replications = k = 1,2

O = Subjects = = 1,2,3,4,5

LO = Speed and Operator interaction

LT = Speed and Time Period Interaction

OT = Operator and Time Period Interaction

y_3 = Dependent Variable of Galvanic Skin Response

y_5 = Dependent Variable of the Difference Between Systolic and Diastolic Blood Pressure

y_6 = Dependent Variable of Systolic Blood Pressure

y_7 = Dependent Variable of Diastolic Blood Pressure

y_8 = Dependent Variable of Heart Sound

SP = Split-Plot

MP = Main Plot

Res = Residual

GSR = Galvanic Skin Response

Dias = Diastolic Blood Pressure

HS = Heart Sound

BP = Blood Pressure

t_0 = First Time Period

t_{wi} = Work Time Period number i (i = 1,2,3,4,5,6)

t_{ri} = Rest Time Period number i (i = 1,2,3,4,5,6)

CHAPTER I

INTRODUCTION

The motivation for this research was the result of a major research effort in the area of physiological costs in industrial environments conducted in the School of Industrial Engineering under the direction of Dr. David C. Ekey, principal investigator.

Industrial engineers since the time of Frederick W. Taylor have been trying to quantify the amounts of work being done by the industrial worker and the factors influencing his work. When the amount of work, or physical energy expended, on a certain job has been determined, it is possible to measure a man's capacity for this type of work, arrive at adequate bases for remuneration, and optimize the work schedule to minimize fatigue and increase productivity.

If it were possible to measure quantitatively physical energy expenditure, it is conceivable that industrial methods of work performance and evaluation would be changed considerably, since most of the subjective measures now incorporated would no longer be acceptable grounds for arbitration. A valid standard could be set for wage scales, work periods, and rate of work. Union grievances should be reduced and personnel's adaptability to various jobs could be determined.

At this time however, no quantitative and operational method for measuring work has been determined. Many different methods of measuring work are presently being used and studied. These can be grouped into the seven following classifications:[1] (1) time study, (2) standard data, (3) predetermined elemental times, (4) activity ratios, (5) bargaining, (6) past records, and (7) experimental procedures.

In time study, two basic weaknesses become apparent. First, the worker is rated as to his pace. This is strictly a subjective measure, yielding results only as valid as the ability of the rater. Second, allowances are added to the times to compensate for worker delays due to fatigue, personal delays, and unavoidable delays. These allowances are usually arrived at by convention and are seldom true indicators of the actual situations.

Standard data built up of elemental times is often useful in determining standards but also has several subjective weaknesses. First, the analyzer must decide which method or type of data he intends to use in synthesizing the job at hand. It is often the case that different methods give different results indicating weaknesses in either the application or the system. Second, it is often very difficult to break down the job at hand into the elements available in the standard system.

"Activity ratio studies are based upon a series of snap observations of activities and require neither timing nor rating the operator," says Belcher.[2] This sampling technique could find some use in actual quantitative physical exertion determination but shows some weakness due to its subjective nature.

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[1]David W. Belcher, Wage and Salary Administration, Englewood Cliffs, N. J., Prentice-Hall, Inc. (1959): 350-60.

[2]Belcher, *op. cit.*, p. 357.

Predetermined elemental times is a more uniform method of standard data but suffers from similar weaknesses.

Bargaining is often used in deciding work or job content, but actually can not yield quantitative results of actual physical work content in anything but compromise terms since the debate is based on subjective bargaining information.

Past performance records can give information in certain instances; however, using these case studies as indicators of other jobs can be misleading. The working conditions affecting the original data are usually only assumed similar and the true causal factors are only hypothesized.

Experimental procedures aimed at quantifying work measurement have been manifested largely in the form of fatigue studies. The term "fatigue" is not easily defined. Some experimenters define it in terms of mental, physiological and work fatigue,[3] while others such as Muscio[4] have stated that due to the ambiguity of the term, the term "fatigue" should not even be used in exact scientific literature. It is evident that a definition must be arbitrarily chosen that will fit the existing situation under consideration. The definition used in this study is that of Bartlett,[5] which states, "Fatigue is a term used to cover all those determinable

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[3]Morris Viteles, Industrial Psychology, New York, W. W. Norton and Company, 1932, pp. 438-63.

[4]B. Muscio, "Is a Fatigue Test Possible?" British Journal of Psychology, 12 (1921-2): 31-46.

[5]Bartlett, "Psychological Criteria of Fatigue," Symposium on Fatigue, W. F. Floyd and A. T. Welford editors, H. K. Lewis and Co., Ltd., London, 1953.

changes in the expression of an activity which can be traced to the continuing exercise of that activity under its normal operational conditions, and which can be shown to lead, either immediately or after delay, to deterioration in the expression of that activity, or, more simply, to results within the activity that are not wanted." The activity cited in the above definition will, in this study, not be directly mental, but physical work so that mental or sedentary fatigue will not be evaluated.

Various variables have been experimentally studied in an effort to find a good measure of physical exertion. Perhaps the most notable success has been achieved by L. A. Brouha at the Haskell Laboratory of E.I. DuPont Company and by the Max-Plank-Institut fur Arbeitsphysiologie in Germany.

A brief resume of some of Brouha's more noteworthy work follows. Physiological reactions at rest, work, and during recovery periods are influenced by wet and dry bulb temperature.[6] The physiological cost of work can most practically and reliably be measured by determining the oxygen consumption and the rate of change of heart rate of the subjects.[7] Without adequate rest periods, workers have a statistically significant increase in body temperature and heart rate at the end of an eight hour day, which is rectified if the proper rest periods are interspersed

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[6] L. A. Brouha, Man's Physiological Reaction to Heat, Haskell Laboratory, E. I. DuPont Co., 1958.

[7] L. A. Brouha, "Physiological Approach to Problems of Work Measurement," 9th Annual Industrial Engr. Inst., Feb., 1957.

throughout the work day.[8] Normally, no measure of pulse rate, "sitting" diastolic, or systolic blood pressure taken at rest is indicative of the amount of hard work a young man can do.[9] Wide differences in physical efficiency is observed between young men who are classified as physically fit on a physical fitness test. The average physical efficiency index is higher with a smaller range for men who regularly engage in muscular activity.[10] Physiological measurements on normal young men show marked variations from individual to individual. Measurements on individuals during two different standardized tasks also show marked individual variations.[11]

The Max-Plank Institut employs three methods of measuring work: (1) an exact time study, (2) the respiration gas-meter, and (3) a continuous pulse rate of the subject during the day.[12] They have achieved usable results using pulse rate and the respiration gas-meter, which shows how many calories the subject is burning while working. In

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[8] L. A. Brouha and M. V. Ball, "Research on Industrial Fatigue," Review of Canadian Biology, Aug., 1948, pp. 479-83.

[9] L. A. Brouha and C. W. Heath, "Resting Pulse and Blood Pressure Values in Relation to Physical Fitness in Young Men," New England Journal of Medicine, April, 1943, pp. 473-77.

[10] L. A. Brouha, N. W. Fradd, B. M. Savage, "Studies in Physical Efficiency of College Students," Research Quarterly, Oct., 1944, pp. 211-24.

[11] L. A. Brouha and B. M. Savage, "Variability of Physiological Measurements in Normal Young Men at Rest and During Muscular Work," Review Canadian Biology, March, 1945, pp. 131-43.

[12] G. Lehman, "Physiological Measurements as a Basis of Work Organization in Industry," Ergonomics, Aug., 1958 pp. 329-44.

addition, they have shown that the pulse rate is directly affected by environmental temperature. With a nomogram developed by De V. Weir, the results of this gas-meter, which is very simple to use and is not too bulky, give a fairly good estimation of the physiological cost of work.[13]

Ingenohl,[14] has shown that the average man's energy reserve is only about twenty-five calories and once this reserve has been used, the man cannot work at his normal pace since the body is using energy which is required to replenish this reserve. He also shows the rest periods needed to restore the reserve and thus the best physiological rest periods. This information along with that available from the gas-meter is surely a worthy advancement in the field of work measurement. Anson,[15] however, says, "It is clear that the characteristics which a time study engineer assesses are not measured by the oxygen cost per minute.... the error in determining the standard effort (by oxygen cost measurement) is of the same order as the errors in time study rating."

Various other methods of work measurement include eye-blink rate, galvanic skin response, and electromyography. King and Michels[16] have

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[13] J. H. Greene, W. H. M. Morris, L. E. Wiebers, "A Method for Measuring Physiological Cost of Work," The Journal of Industrial Engineering, 10 (1959): 180-84.

[14] Ingo Ingenohl, "Measuring Physical Effort," The Journal of Industrial Engineering, 10 (1959): 99-114.

[15] C. J. Anson, "The Physiological Measurement of Effort," Time and Motion Study, Feb., 1954, pp. 26-31.

[16] D. C. King and K. E. Michels, "Muscular Tension and the Human Blink Rate," Journal of Experimental Psychology, 53, (1957): 113-16.

shown that blink rate could be used to indicate muscular tension in a group of people. However, eye-blink rates differ considerably among persons. The blink rate may not be a particularly good index for estimating the degree of tension in any given subject, that is as a criterion to be used in industry as a measure of individual muscle fatigue.

Ross, Dardano, and Hackman[17] found definite trends in conductance (GSR) in groups of subjects participating in a vigilance task. Although no statistically significant relationship was found, it was assumed that high conductance levels are related to high vigilance.

Wilcott and Beenken[18] have shown an essentially linear relationship for females and a slightly curvilinear relationship for males between the force of muscle pull and the integrated mean electromyographic potential (EMG). A stipulation in this study was that the bicep muscle length must remain constant. Small and Gross[19] tested this variable in a weight lifting task in which the muscle was allowed to change in length. They found that the rate of lifting and the weight lifted were both statistically significant in causing the integrated mean muscle action potential to rise.

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[17]Sherman Ross, J. Dardano, R. C. Hackman, "Conductance Levels During Vigilance Task Performance," Journal of Applied Psychology, 43 (1959): 65-69.

[18]R. C. Wilcott and H. G. Beenken, "Relation of Integrated Surface Electromyography and Muscle Tension," Perception and Motor Skills, 7 (1957): 295-98.

[19]A. H. Small, Jr. and N. B. Gross, "Integrated Muscle Action Potentials in a Weight Lifting Task as a Function of Rate and Weight of Lifting," Journal of Comparative and Physiological Psychology, 1 (1958): 227-29.

From a review of the experimental procedures recently conducted, it is apparent that many measurable variables are available in the human body that are potential work measurement indicators. The purpose of this research has been to find an operational variable that could be used in industrial applications as a measure of physical exertion. The purpose of the research discussed in this thesis is to further this experimentation in an effort to find a usable method of determining human energy expenditure.

It is hypothesized that one or more of the variables, heart sound, galvanic skin response, or blood pressures (systolic, diastolic, and their difference) is significantly related to the amount of energy expended by a man.

Young[20] has found that heart rate can be used in predicting the intensity of work on certain experimental tasks. This work along with Brouha's studies show that the heart is definitely one of the variables to study. Heart sound is then the next variable that logically should be investigated. Of the four main sounds emitted by the heart,[21] the two loudest (systolic) sounds were those studied. Through an appropriate electrical network, these two sounds were converted to a voltage response and their combined intensity was recorded as an amplitude. From the previous studies on heart rates, this heart sound amplitude was hypothesized to be a significant indication of physical exertion.

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[20]H. H. Young, "Relationships Between Heart Rate and Intensity of Work for Selected Tasks," Journal of Industrial Engineering, 7 (1956): 300-303.

[21]A. A. Luisada, editor, Cardiology, McGraw Hill, New York, 2 (1959): 3-127.

No information was found in the literature concerning heart sound as an indicator of work measurement. Also, it was not possible to purchase existing commercial equipment that would sum the heart sounds in a manner that would enable the intensity of the total sound to be measured. From these facts, it appears that this research is the first approach at using heart sound in an endeavor towards finding a quantitative indicator of physical exertion.

Galvanic skin response has given encouraging results in vigilance tasks and it was also expected to increase significantly in a physical exertion task. Blank and Finesinger[22] found that GSR increased immediately in a step test. In the present experiment, the exosomatic method of GSR was utilized.[23]

Due to ease of recording, it was decided to record both systolic and diastolic blood pressures in the experiment in an effort to reinforce Brouha's conclusions that blood pressure varied too much among individuals to be of significant value in work measurement. It is noteworthy that both Karpinos[24] and researchers in Great Britain[25] cited

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[22]I. H. Blank and J. E. Finesinger, "Electrical Resistance of the Skin," Archives of Neurology and Psychiatry, 56 (1946): 544-57.

[23]McCleary, "Galvanic Skin Response," Psychological Bulletin, 47 (1950): 97-112.

[24]B. D. Karpinos, "Blood Pressure and its Relation to Height, Weight, Race, and Age - World War II," American Journal of Hygiene, 68 (1958): 288-311.

[25]"Environment and Blood Pressure," British Medical Journal, November 15, 1958, pp. 1208-1209.

that age, sex, height, weight, race, and environment were all factors affecting individual blood pressures.

The task to which the subjects were subjected was a torsion bar provided with a lever arm which was twisted at a given rate in 5 three-minute work periods which were separated with three minute rest periods. Concomitant variables recorded were age, weight, height, weight to height ratio, temperature, relative humidity, time of day and physical fitness (if in obvious superior physical fitness, as an athlete in training).

Five male college students selected at random from a group were used as subjects. Each subject performed the torsion bar task at two speeds and then replicated the two speeds again which brought him to the laboratory a total of four separate times. The data from the tests were then analyzed using analysis of variance with the aid of the IBM 650 digital computer.

During the preceding literature survey, the author was unable to find an operational method of quantitatively determining physical work exertion in humans which would be applicable to the industrial work situation. It is the purpose of the following study to add significant information to this area of research which may eventually be a valuable aid to industrial engineering.

CHAPTER II

A DESCRIPTION OF THE INSTRUMENTATION

The following instruments were used in the experimentation: (1) Heart Sound Amplifier and microphone; (2) Recorder with an electrocardiograph preamplifier and a standard driver amplifier and power supply; (3) Galvanic skin response meter; (4) Torsion bar machine; and (5) Miscellaneous equipment.

Heart Sound Amplifier and Microphone.--The heart sound amplifier was designed by the Waters Corporation to meet the following specifications: (1) amplify the heart sound impulses from the microphone and add the two loudest sounds (systolic); and (2) provide an output that could be recorded in one direction from a base line that would indicate the change in intensity of heart sound as a change in voltage output. The instrument (model HS-10) consists of a three stage transistor amplifier, a high frequency filter, a half-wave rectifier, a full-wave rectifier, and an integrating or summing circuit (Figure 1). A Waters HSM-1 microphone was used to pick up the initial heart sound.

Recorder, Preamplifier, Amplifier, and Power Supply.--A Sanborn four channel recorder (model 154-100B) was used to record the heart sound. This recorder uses D'Arsonval galvanometers which drive recording arms consisting of hot wire ribbons which burn the trace on the black perma-paper recording tape. The Sanborn ECG Preamplifier Model 150-1600 was used in conjunction with the recorder. The Sanborn driver amplifier and power supply (model 150-200B/400) is the standard unit used with the Sanborn recorder.

Galvanic Skin Response Meter.--Galvanic skin response was read from a meter constructed by the author. The circuit is similar to that described by Ross and Dardano.[26] The voltage output of the circuit is adjusted so that one volt appears across each subject electrode. With this arrangement, the microammeter reads directly in conductance (mhos) and with appropriate resisters, the fifty microampere meter will read up to 200 mhos (Figure 1). Copper electrodes of 0.74 inches diameter were used.

Torsion Bar Machine.--The torsion bar machine was designed to provide a task causing the subject's arms to be used in expending a given amount of energy. The following equation was used to determine the force applied by the subject:[27]

$$P = \frac{aD^4G}{583.6\ RL}$$

where a = angle of torsional deflection in degrees

D = diameter of the shaft in inches

G = torsional modulus of elasticity, generally assumed to be 12,000,000 for cold roled steel

R = length of lever arm in inches

L = length of shaft in inches

P = force in pounds.

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[26]Ross and Dardano, op. cit.

[27]Erik Oberg and F. D. Jones, Machinery's Handbook, The Industrial Press, New York, 1942, p. 491.

Figure 1. Recording Apparatus.
A - Heart Sound Amplifier
B - GSR Meter

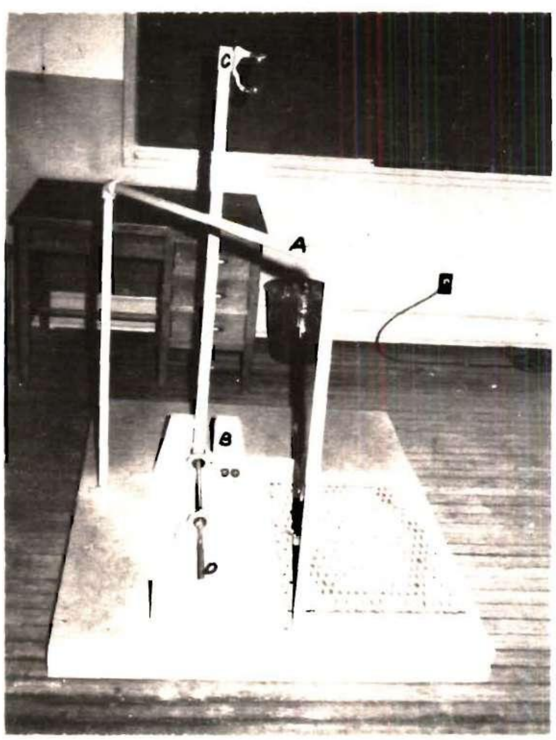

Figure 2. Torsion Bar Machine.
A - Hand Rail
B - Stops
C - Lever Arm
D - Torsion Bar

The lever arm was set at fifty inches and the five-eights inch bar was twisted fifteen degrees with an effective length (between welds) of thirty-four inches (Figure 2). The force required for each pull was therefore 27.7 pounds and the work was 15.0 foot pounds. At the slow rate of pulls, 50 per minute, the subjects expended 755.0 foot pounds per minute of energy or 0.023 horsepower, and at the fast rate, 100 pulls per minute, 1510.0 foot pounds per minute or 0.046 horsepower of energy was expended.

Miscellaneous Equipment.--Relative humidity was read from a Taylor Humidiguide and temperature was recorded from a Weston Laboratory Thermometer. A Franz Electric Metronome was used in providing a visual and audible beat for the subjects to follow in order to pull the torsion machine at a uniform and constant rate. A Minerva decimal minute stop watch was used to keep track of the three-minute work and rest periods which were of interest in recording the experimental data. The dependent blood pressure variables were recorded after measurement with a Riester aneroid sphygmomanometer and stethoscope.

CHAPTER III

EXPERIMENTAL DESIGN AND PROCEDURE

The purpose of this chapter is to describe the design of the experiment, explain the variables, and describe the experimental approach.

Subjects.--Five male college students were randomly selected (i.e., from a fraternity group of sixty students, five were selected by drawing numbers) as subjects to work on the torsion machine. All five of the subjects were right handed. They all previously had passed the Georgia Tech physical fitness tests, and had been subjected to the physical education required of all such students. Although no remuneration was available, all of the subjects appeared willing to cooperate to the fullest extent. No formal individual motivation was introduced.

Speeds.--The speed sequence at which the subjects worked, i.e., slow first or fast first, was randomized for each of the replications of the experiment. Each subject worked three minutes and rested three minutes, worked three and rested three, etc., until he had worked 5 three-minute periods and rested 5 three-minute periods at each speed. Readings of the dependent variables were taken prior to the start of the first work period to give a starting point so that a total of six sets of readings were taken giving six periods of rest and work which completed the work cycle (Figure 3). The rest period data is not considered in this thesis. After each subject had completed work cycles at the slow and fast speeds, the experiment was replicated with the order of the speeds again randomized. Work periods for each subject were held a minimum of one day apart so that no subject completed more than one work cycle each day. See Figure 4 for a diagram of the main effects (subjects, time, replication, and speed).

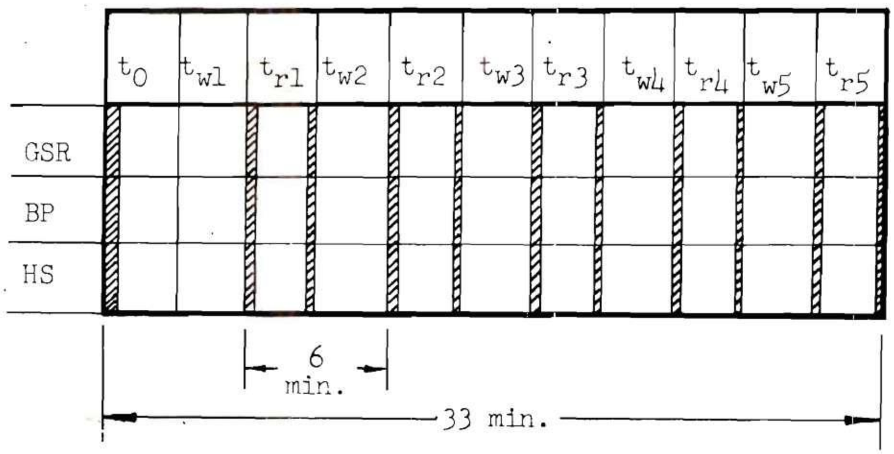

Figure 3. Subject Work Cycle.
(Crosshatching indicates recording times)

	Replication 1												Replication 2											
	Speed 1						Speed 2						Speed 1						Speed 2					
	t_0	t_1	t_2	t_3	t_4	t_5	t_0	t_1	t_2	t_3	t_4	t_5	t_0	t_1	t_2	t_3	t_4	t_5	t_0	t_1	t_2	t_3	t_4	t_5
O_1																								
O_2																								
O_3																								
O_4																								
O_5																								

Figure 4. Experimental Design.

Concomitant Variables.--The concomitant variables recorded were temperature, relative humidity, time of day, subject height, subject weight, subject weight to height ratio, subject age, and subject physical fitness. Temperature was recorded at the beginning and end of each work cycle and ranged from a high of 87.5 to a low of 74.1 degrees Fahrenheit. Relative humidity was recorded at the beginning and end of each work cycle with a range of 65.5 to 42.5 per cent. Subjects' work periods were scheduled to start at their convenience, from eight A.M. to as late as six P.M. Subject heights ranged from 66 to 74 inches with a weight range of 150 to 190 pounds while subject weight to height ratio varied from 2.64 to 2.12 pounds per inch of height. Ages ranged from eighteen to twenty-eight years. Since one subject was a weight lifter and in apparently superior physical fitness, he was placed in a separate class from the other subjects (Table 1). The dependent variables studied were heart sound, blood pressure (systolic, diastolic, and their difference), and galvanic skin response.

Table 1. Operator Concomitant Data

Operator No.	Age	Height	Weight	Fitness	Wt./Ht.
O_1	19	70"	185 #	1	2.64 #/in.
O_2	21	72"	153 #	0	2.12 #/in.
O_3	18	66"	150 #	0	2.27 #/in.
O_4	28	74"	190 #	0	2.57 #/in.
O_5	20	70"	165 #	0	2.36 #/in.

Environmental conditions during the experimentation were as follows. The second floor room in which the experiments were conducted was approximately twenty feet wide by thirty feet in length. The ceiling and upper half of the walls were painted light pea green while the lower portion of the walls were medium green in color. The windows in the room were on the south wall so that the sun never shone directly into the room and onto the subjects. The windows were opened throughout the entire experiment as were the ventilation louvers on the tops of the doors. The doors were closed throughout the experiments for privacy although at times subjects not under study at that particular time were present during other subject's experiment periods. Lighting was provided by daylight and fluorescent lighting fixtures. The noise level was that of a normal classroom as the experimentation room was previously used as a classroom in the School of Industrial Engineering Building on the Georgia Tech campus. The experiments were conducted during the month of May, 1960.

Procedure.--The experimental procedure employed for each subject was identical so that it will suffice to explain the procedure for one subject.

According to a prearranged schedule for the entire experiment, the subject arrived at the laboratory at the beginning of the hour. All subjects were instructed to wear gym shorts and hard soled shoes. They changed into these clothes immediately after arrival and rested for a minimum of ten minutes. (Usually they sat in a straight backed chair provided for this purpose.) The subjects were instructed on the general nature of the experiment, but the specific objectives, measurements, and performance factors were not discussed. They were, if curious (and some were) permitted to come and go in the laboratory as they pleased -- when not working. When the experiment was completed, the subjects were given access to the results. He then mounted the torsion machine and the author and an assistant taped the recording apparatus to his body in the following manner. The blood pressure cuff was taped to his upper left arm so that it was always in position to inflate. The copper GSR electrodes were coated with standard Sanborn Redux paste and then taped to the palms of his hands. The heart sound microphone, encased in foam rubber for protection and to muffle out extraneous sounds, was then taped to a rubber chest band placed around the subject's chest to insure firm contact of the microphone with the chest (Figure 5). The chest location yielding the loudest sound of each subject's heart was predetermined with a stethoscope and the position marked with ink so that the microphone could be placed in the optimum pick up position with minimum delay.

With the apparatus satisfactorily in position, the subject was told to stand on foot-print marks on the torsion machine to insure uniformity among subject's position and between different cycles. His left hand was placed on the arm rail and the subject was ready to start working. Room temperature and relative humidity were recorded and then the metronome was turned on. The metronome had been set at the proper speed before the subject arrived, and although he recognized the slow or fast speed, he was not told that twice the energy was being expended in the fast speed.

Figure 5. Heart Sound Microphone Taped to the Subject's Chest.

GSR, heart sound, and blood pressure readings were taken preceding the work periods. The heart sound was taken in the following manner. The recorder was calibrated so that one millivolt of input from the microphone caused the recorder stylus to move with an amplitude of one centimeter and the recording tape was moved at twenty-five millimeters a second for approximately five seconds during each recording period. The GSR and blood pressure were read directly from the instruments and a written record was made.

After the first readings of all dependent variables had been taken, the subject was told to start pulling the lever arm on the torsion machine at the same rate as the metronome signals. After three minutes of work had elapsed, the subject was instructed to stop and readings of the dependent variables were immediately taken by the author and his assistant (Figure 6). The subject then rested for three minutes at the end of which time readings of the variables were again taken. The subject then repeated the task for three minutes and readings were taken in the same manner. This procedure was followed until the subject had completed five work periods (Figure 3). Data were collected at the end of the fifth work period and again after three minutes of rest.

At the end of the test period (thirty-three minutes) temperature and relative humidity were again recorded, the recording apparatus were removed from the subject, and he was excused until the next work period. This same procedure was followed for the four work periods of each of the five subjects.

Figure 6. Dependent Variables Being Recorded.

CHAPTER IV

ANALYSIS AND RESULTS

In order to evaluate the effects of the two speeds, the set of three minute work periods, and the replications on the dependent variables among the five subjects, a split-plot factorial design was used. It is seen from Figures 3 and 4 that this design incorporates a split-plot for the time variable, while the speeds, replications, and subjects form the main plots. It should be noted that some precision is gained in finding the significance of the time effect by the split-plot design.

The data for the dependent variables were recorded and coded in the following manner. Heart sound data were obtained by averaging four amplitudes (in millimeters) from each reading (Figure 7). These amplitudes were arbitrarily selected on a quality basis, i.e., some sound waves were distorted by extraneous noises such as the subject coughing.

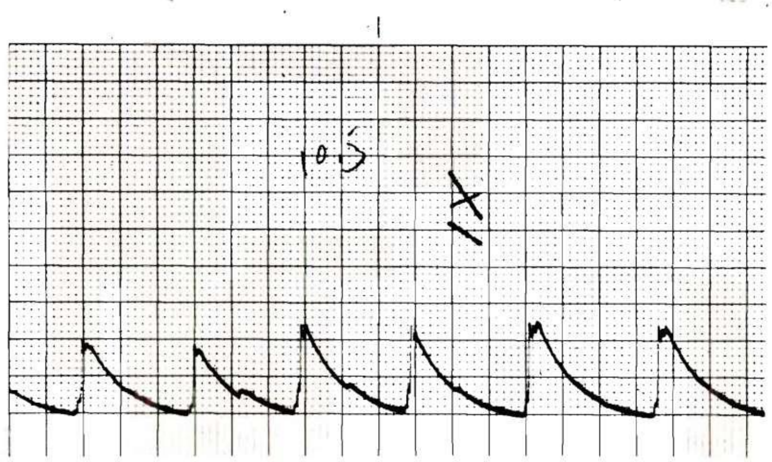

Figure 7. Heart Sound Recording Tape.

This average was then multiplied by ten and increased by 64 to form the code. Heart sound was called independent variable "y_8". Galvanic skin response was read in mhos at the end of each three minute work period. These readings were multiplied by ten and reduced by 59 to form the coded data. GSR was called dependent variable "y_3". Three different measures of blood pressure were analyzed. Systolic, diastolic, and the difference between systolic and diastolic pressures were recorded. Systolic, "y_6", was reduced by 66 to form the coded data while diastolic, "y_7", was reduced by 30 to form its code and the difference between uncoded systolic and diastolic, "y_5", was reduced by 22 to form that code.

Table 2 is a breakdown of the analysis showing the sums of squares for each source of variation including the interactions.

The actual values of the mean squares for each dependent variable (coded) are shown in Table 3. Table 4 shows the values for the F ratio of each variable and the five and one percentage point values of the F distribution for these ratios.[28]

Results.--From Table 4, it is seen that replication, speed and the speed and operator interaction were not significant under the conditions of this experiment. Differences among operators, however, did cause a significant difference in the readings of both systolic and diastolic blood pressure. Also, the six time periods significantly affected the GSR, heart sound, and the difference in blood pressures readings while

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[28]A. H. Bowker and G. J. Lieberman, Engineering Statistics, Prentice-Hall, Inc., Englewood Cliffs, N. J., 1959, p. 560.

Table 2. Split-plot Experimental Design. Sources of Variation.

Source	D.F.	Sums of Squares
R	1	$\sum_{k} T^2_{..k.}/60 - T^2_{....}/120$
L	1	$\sum_{i} T^2_{i...}/60 - T^2_{....}/120$
O	4	$\sum_{\ell} T^2_{...\ell}/24 - T^2_{....}/120$
LO	4	$\sum_{i\ell} T^2_{i..\ell}/12 - \sum_{i} T^2_{i...}/60 - \sum_{\ell} T^2_{...\ell}/24 + T^2_{....}/120$
(RL+RO+LRO)*	9	$\sum_{ik\ell} T^2_{i.k\ell}/6 - \sum_{k} T^2_{..k.}/60 - \sum_{i\ell} T^2_{i..\ell}/12 + T^2_{....}/120$
T	5	$\sum_{j} T^2_{ij..}/20 - T^2_{....}/120$
LT	5	$\sum_{ij} T^2_{ij..}/10 - \sum_{j} T^2_{.j..}/20 - \sum_{i} T^2_{i...}/60 + T^2_{....}/120$
OT	20	$\sum_{j\ell} T^2_{.j.\ell}/4 - \sum_{j} T^2_{.j..}/20 - \sum_{\ell} T^2_{...\ell}/24 + T^2_{....}/120$
(RT+RLT+ROT+ROTL+OTL)**	70	$\sum_{\ell} T^2_{...\ell}/24 + \sum_{i} T^2_{i...}/60 + \sum_{j} T^2_{.j..}/20 - \sum_{ik\ell} T^2_{i.k\ell}/6 - \sum_{ij} T^2_{ij..}/10$ $- \sum_{j\ell} T^2_{.j.\ell}/4 + \sum_{ijk\ell} y^2_{ijk\ell} - T^2_{....}/120$
Total	119	$\sum_{ijk\ell} y^2_{ijk\ell} - T^2_{....}/120$.

*Main Plot Residual **Split-Plot Residual

Table 3. Mean Square Values

Source	Variable				
	y_3	y_5	y_6	y_7	y_8
R	307,547.625	7.500	310.408	418.133	5,280.133
L	118.008	16.133	69.008	124.033	489,218.700
O	265,072.979	298.779	1,328.854	1,046.593	208,824.804
LO	175,250.279	112.196	98.404	66.721	112,110.554
T	68,786.908	77.500	38.588	25.993	70,736.593
LT	4,146.588	40.553	57.548	4.233	22,782.860
OT	2,641.404	56.229	55.634	32.506	16,254.664
SP Res.	4,002.404	33.936	45.059	15.935	7,653.740
MP Res.	99,456.477	185.259	210.534	144.652	115,580.819

the speed and time periods interaction was significant in affecting heart sound. The interaction between operators and the time periods was a significant influence on the diastolic blood pressure readings as well as those of heart sound under the conditions of this experiment. A brief discussion of these relationships will follow for each source.

Replicating the experiments did not significantly affect any of the dependent variables. These results indicate that the error among trials was apparently well controlled.

As was pointed out in the introduction, blood pressure was expected to vary significantly among workers. Under the conditions of this experiment, both systolic and diastolic blood pressure varied significantly among workers (diastolic at the 0.01 level of significance); however, the difference between systolic and diastolic pressures was not significantly affected by the various operators. See Figures 8 and 9 for the

Table 4. Analysis of Variance Data

Source	Variable	Error Mean Square	D.F.	5% F Value	1% F Value	Ratio Value
R	y_3	Res. MP	1/9	5.12	10.6	3.09
R	y_5	Res. MP	1/9	5.12	10.6	0.40
R	y_6	Res. MP	1/9	5.12	10.6	1.47
R	y_7	Res. MP	1/9	5.12	10.6	2.89
R	y_8	Res. MP	1/9	5.12	10.6	0.05
L	y_3	LO	1/4	7.71	21.2	0.001
L	y_5	LO	1/4	7.71	21.2	0.14
L	y_6	LO	1/4	7.71	21.2	0.70
L	y_7	LO	1/4	7.71	21.2	1.86
L	y_8	LO	1/4	7.71	21.2	4.36
O	y_3	Res. MP	4/9	3.63	6.42	2.67
O	y_5	Res. MP	4/9	3.63	6.42	1.61
O	y_6	Res. MP	4/9	3.63	6.42	6.31*
O	y_7	Res. MP	4/9	3.63	6.42	7.24**
O	y_8	Res. MP	4/9	3.63	6.40	1.81
LO	y_3	Res. MP	4/9	3.63	6.42	1.76
LO	y_5	Res. MP	4/9	3.63	6.42	0.61
LO	y_6	Res. MP	4/9	3.63	6.42	0.47
LO	y_7	Res. MP	4/9	3.63	6.42	0.46
LO	y_8	Res. MP	4/9	3.63	6.42	0.97
T	y_3	OT	5/20	2.71	4.10	26.04**
T	y_5	OT	5/20	2.71	4.10	1.38
T	y_6	OT	5/20	2.71	4.10	0.69
T	y_7	OT	5/20	2.71	4.10	0.80
T	y_8	OT	5/20	2.71	4.10	4.35**
LT	y_3	Res. SP	5/70	2.35	3.29	1.04
LT	y_5	Res. SP	5/70	2.35	3.29	1.19
LT	y_6	Res. SP	5/70	2.35	3.29	1.28
LT	y_7	Res. SP	5/70	2.35	3.29	0.27
LT	y_8	Res. SP	5/70	2.35	3.29	2.98*
OT	y_3	Res. SP	20/70	1.72	2.15	0.66
OT	y_5	Res. SP	20/70	1.72	2.15	1.66
OT	y_6	Res. SP	20/70	1.72	2.15	1.23
OT	y_7	Res. SP	20/70	1.72	2.15	2.04*
OT	y_8	Res. SP	20/70	1.72	2.15	2.12*

*Significant at the 5% level.

**Significant at the 1% level.

curves of average results. Also, GSR and heart sound were not significantly affected by the difference among cperators.

One of the more interesting results of the experiment was the effect on the dependent variables due to the two speeds. It was expected that speed would be one of the most significant sources of variation since exactly twice the energy was expended in performing the task at the fast speed than at the slow speed. However, speed had no significant influence on the dependent variables under the conditions of this experiment. An explanation of this result could be that even fast speed did not require sufficient energy expenditure of the subjects to affect the dependent variables measured. This could be classified as a sub-threshold work load with respect to these variables. Therefore, in order for these variables to be useful indicators of load or energy expenditure, the amount of work would have to be increased.

Probably the most important results of this research was the significance of the six time periods within each work cycle. The linear component of the effects of the time variable was significant at the 0.005 percentage level of confidence for both GSR and heart sound (Tables 5 and 7). At the 0.05 percentage level of confidence, time periods showed a quadratic relationship to the difference between systolic and diastolic blood pressure. The least squares[29] estimate of this relationship was $y = 40.67 + 0.506t - 0.016t^2$, where y is the difference in pressures. These relationships tend to show, at least on these three

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[29] Frank Yates and R. A. Fisher, Table XXlll, "Orthogonal Polynomials," Statistical Tables for Biological, Agricultural and Medical Research, Hafner Publishing Co., New York, 1953, p. 80.

variables, that a low level of energy output, fatigue could be independent of the threshold force applied but still be related to the time this force is applied (Figures 13, 14, and 15). This could have noteworthy significance in industrial applications where fatigue curves can not be constructed, at present, due to the light nature of the existing work.

The interaction between operators and time showed a significant effect on both diastolic blood pressure and heart sound (Figures 11 and 12 and Table 7). This significance was anticipated since at least one of the operators was in apparently superior physical condition. He would therefore be expected to complete the task with less physical strain and less change in the dependent variables than the other subjects. It is important to note that since GSR and the difference between systolic and diastolic blood pressures were not significant, these variables could be very valuable in further work in that it might not be necessary to stratify the subjects or workers into groups according to their apparent physical fitness.

The interaction between operators and speed, contrary to anticipation, showed no statistical significance to the dependent variables measured. This is probably explained by the same reasoning used in the lack of significance showed by speed in that the task was too easy to cause noticeable fatigue in the subjects relative to the amount of force they were exerting.

Speed and time interacted significantly on the variable of heart sound (Figure 10 and Table 6 and 7). Again significance was expected from this interaction, since speed and time would be the two main factors involved in physical fatigue. While the speed alone was sub-threshold and non-significant within the limits of this experiment, it was sufficient to interact with time. If the work time period had been extended, e.g., eight hours, one would suspect that this interaction would remain significant and also that the main effect of speed would be significant.

Note, also, that time and the speed x time interaction were split-plot variables and thus had a smaller residual variance and therefore could reach significance easier than the speed main effect which was a whole-plot variable.

The standard deviations of the five dependent variable values for the main plot and split-plot errors are as follows. For the split-plot error, which consists of the six time periods, the standard deviations were: GSR - 20.0 mhos; the difference between systolic and diastolic blood pressures - 5.8 millimeters of Mercury; systolic blood pressure - 6.7 millimeters of Mercury; diastolic blood pressure - 4.0 millimeters of Mercury; and heart sound - 27.7 millimeters. The main plot error standard deviations were: GSR - 39.9 mhos; the difference between systolic and diastolic blood pressures - 5.0 millimeters of Mercury; systolic blood pressure - 5.3 millimeters of Mercury; diastolic blood pressure - 4.6 millimeters of Mercury; and heart sound - 42.4 millimeters.

Table 5. Multiple Order Relationships

Order	Time Mean Squares to Operator x Time Interaction Mean Squares				
	y_3	y_5	y_6	y_7	y_8
Linear	128.172*	0.148	0.065	0.134	17.068*
Quadratic	0.513	4.404*	0.012	2.386	3.498
Cubic	0.419	2.238	1.586	1.089	0.939
Quartic	1.101	0.064	1.504	0.343	0.007
Quintic	0.005	0.037	0.002	0.043	0.248

5% F Value = 4.35

*significance of the 5% level

Table 6. Multiple Order Relationships

Order	Speed x Time Interaction Mean Squares to Split-Plot Residual Mean Squares				
	y_3	y_5	y_6	y_7	y_8
Linear	2.972	0.049	0.076	0.151	9.755*
Quadratic	1.112	0.257	1.779	0.257	3.090
Cubic	0.896	3.863	3.570	0.264	1.987
Quartic	0.168	1.762	0.088	0.503	0.051
Quintic	0.032	0.044	0.896	0.153	0.001

5% F Value = 3.98

*significance at the 5% level

Table 7. Least Squares Curves and Correlations

Source	Variable	Equation	Correlation Coefficient
T	HS	$y = 0.470t + 11.627$	0.757
T	GSR	$y = 0.502t + 31.264$	0.840
L_1T	HS	$y = 7.127t + 143.767$	0.720
O_1T	Dias. BP	$y = 0.126t + 70.190$	0.424
O_2T	Dias. BP	$y = 0.070t + 70.405$	0.537
O_3T	Dias. BP	$y = -0.060t + 61.810$	-0.412
O_4T	Dias. BP	$y = 0.261t + 67.881$	0.761
O_5T	Dias. BP	$y = -0.312t + 63.095$	-0.727
O_1T	HS	$y = 0.034t + 5.238$	0.371
O_2T	HS	$y = 0.562t + 7.560$	0.809
O_3T	HS	$y = 0.010t + 17.755$	0.009
O_4T	HS	$y = 1.239t + 10.871$	0.555
O_5T	HS	$y = 0.754t + 11.406$	0.843

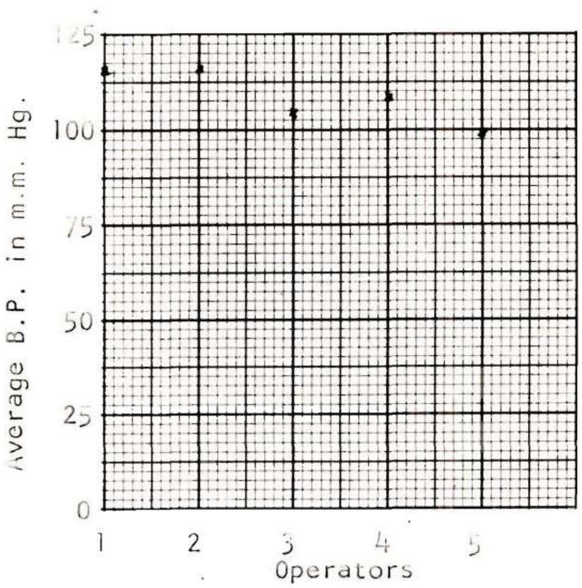

Figure 8. The Effect of 0 on Systolic Blood Pressure.

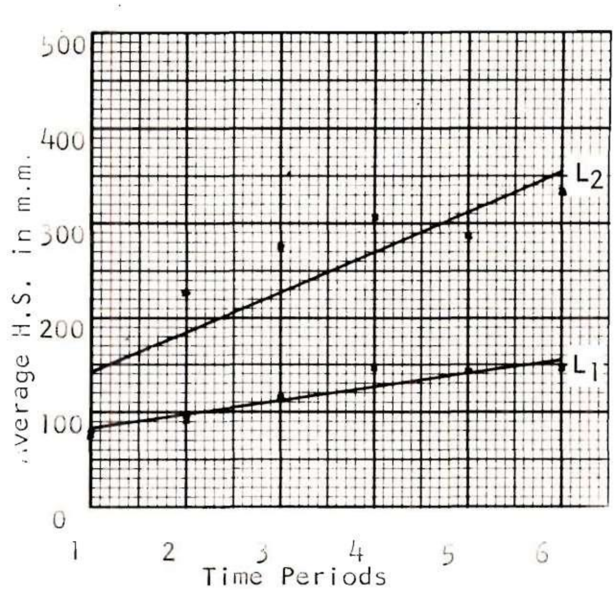

Figure 10. The Effect of the LT Interaction on Heart Sound. ("x's" are the original points and the curve is the regression line.)

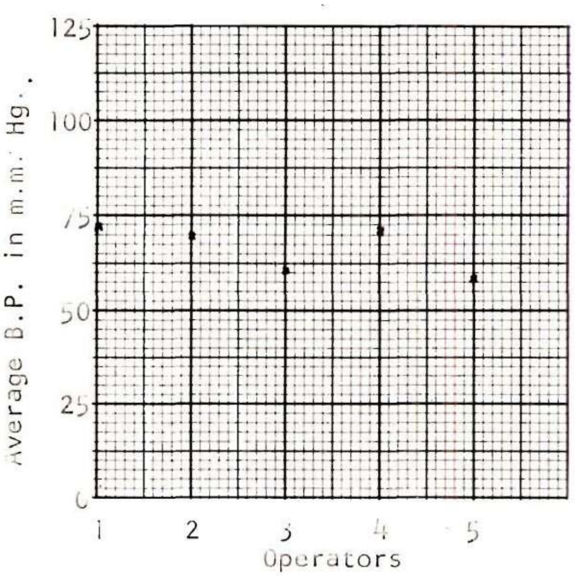

Figure 9. The Effect of 0 on Diastolic Blood Pressure.

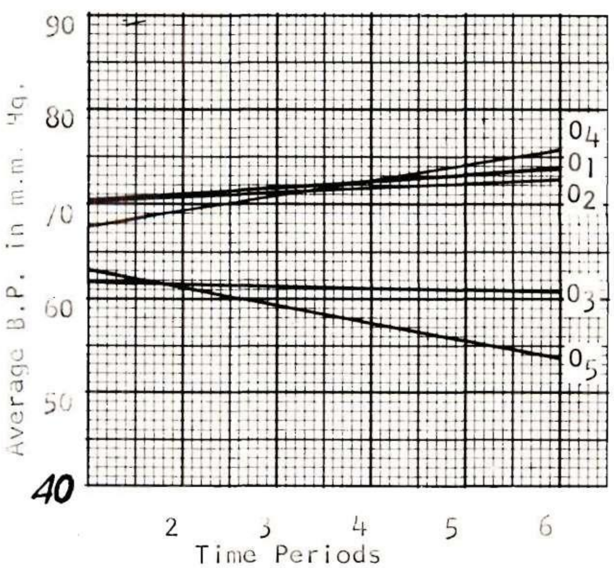

Figure 11. The Effect of the OT Interaction on Diastolic B.P.

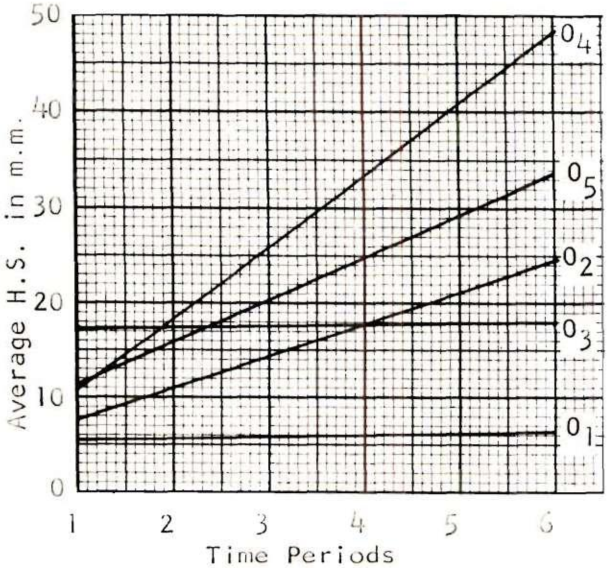

Figure 12. The Effect of the OT Interaction on Heart Sound.

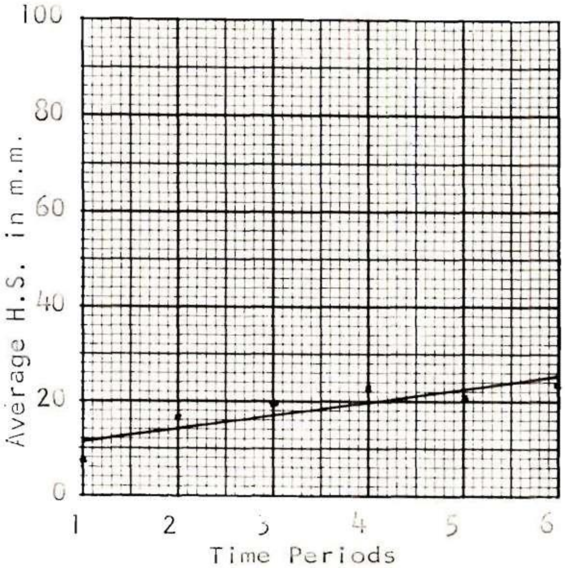

Figure 14. The Effect of T on Heart Sound. ("x's" are the original points and the curve is the regression line.)

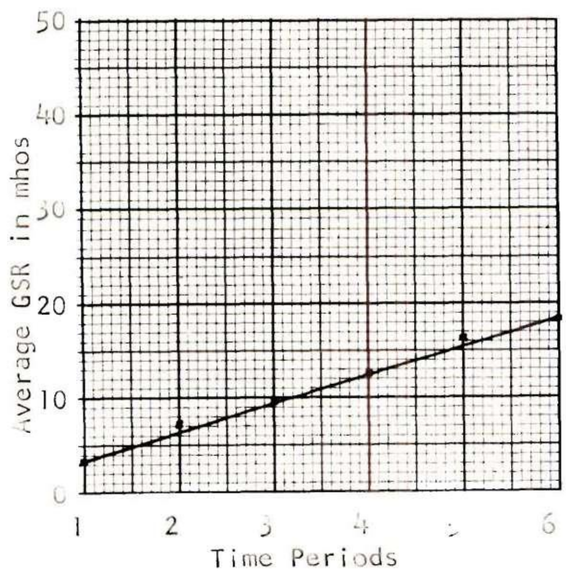

Figure 13. The Effect of T on GSR. ("x's" are the original points and the curve is the regression line.)

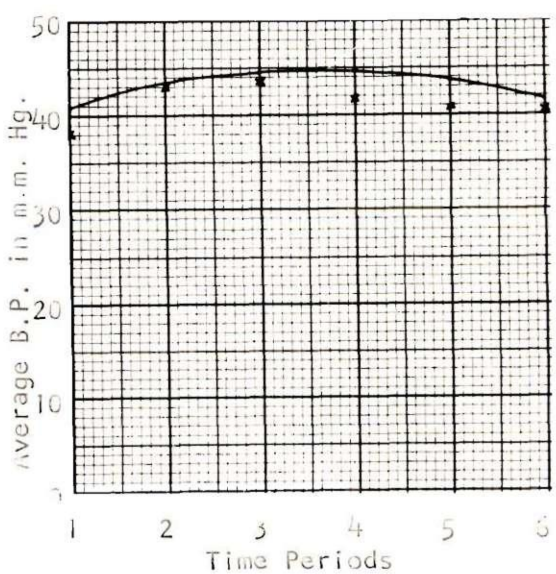

Figure 15. The Effect of T on the Differences Between Blood Pressures. ("x's" are the original points and the curve is the regression line.)

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The results from this experiment indicate that in tasks involving light physical work for a short period of time, which could be classified as sub-critical in that there is no appreciable change in GSR and heart sound due to the intensity of the work, time of work is the factor responsible for fatigue. Also, galvanic skin response and heart sound, under the conditions of this experiment, increase linearly as the work periods progress.

In industrial applications, it appears that more thought should be given to the time on certain tasks involving relatively small energy outlays previously thought too small to add significantly to fatigue. An analogy could be drawn to a powerful 400 horsepower car cruising over small hills. At the start, the car would not consume appreciably more fuel on the small hills than on level land. However, if the car continued this cruising until the 10,000 mile checkup time was nearing, it would probably be found that the car was using more fuel than previously. The same car travelling over large mountains would use more fuel. The person, although seemingly performing effortless work, does, in time, become fatigued, i.e., expending energy at a "cruising rate," but would expend significantly greater amounts of energy on work involving more severe physical exertion. It should follow that his performance could reduce in accuracy and speed if proper rest (time to replenish used energy) is not permitted. In jobs of this light nature, GSR and heart sound probably are accurate indicators of fatigue and certainly should be studied further to validate the results of this experiment. It is recommended that different experimental conditions be used involving longer work cycles.

Another encouraging result of this experiment was the relationship between operators and blood pressure. Although statistically significant differences were found in both systolic and diastolic pressures among different subjects, no significant variance was found among subjects for the difference between systolic and diastolic blood pressures. This latter lack of significance could be attributed to the low energy output in this experiment; however, this has not been shown and one is encouraged to consider this variable for work measurement among operators. This variable should be tested under conditions requiring larger energy expenditures of the subjects and longer work cycles.

Another industrial application of the results of this research could be that on jobs requiring sub-critical energy expenditures, little importance might be attached to the actual amount of energy expended as long as it is sub-critical and fatigue is measured on a time basis. Naturally, more study is necessitated in order to define more clearly the limits of this critical region below which different amounts of work are of little importance fatiguewise. As was previously stated, under the conditions of this experiment, the significant factor affecting the measured variables was the length of time the work was carried out. The load-time interaction, however, significantly affected GSR.

It should be pointed out that heart sound, as recorded in this experiment, could not be called operational. Uncontrollable noises such as coughing or loud talking caused the heart sound recordings to contain extraneous sounds, not emitted by the heart. In an industrial application, it would be equally difficult to control these noise levels in an effort to keep the heart sound tracings free from extraneous sounds. Although the sounds emitted by the heart can be recognized from other sounds present, some skill is required in making a positive interpretation of the recordings. Therefore, until better methods of heart sound recording are determined, the use of this variable should be confined to the laboratory.

Future research carried out in this area should also consider longer lengths of work. The total of fifteen minutes work by each subject during each work cycle in this experiment could have yielded results considerably different if the work had been continued throughout an eight hour work day. One such experiment could have the subjects performing tasks involving different muscle groups for extended periods of time and at many different levels of energy expenditure. Also, persons of varying physical fitness, age, etc., should be considered in order to possibly find the different ranges of change to expect in measured dependent variables (GSR, heart sound, etc.) for the above suggested classes of operators at different work levels.

A P P E N D I X

PART I

Original Uncoded Data

y_3 in mhos - Replication 1

	Load - 1						Load - 2					
	T_0	T_1	T_2	T_3	T_4	T_5	T_0	T_1	T_2	T_3	T_4	T_5
O_1	31.8	34.0	38.0	40.2	44.0	42.4	22.0	26.2	32.2	23.0	26.8	31.2
O_2	11.5	20.5	24.5	23.5	23.0	28.2	10.0	11.1	15.0	17.5	13.0	15.0
O_3	26.4	22.0	24.0	22.0	32.0	35.0	55.0	55.6	55.0	47.0	48.0	52.0
O_4	46.0	44.0	48.0	54.4	50.0	54.0	38.0	42.0	32.0	38.0	38.0	36.0
O_5	27.0	30.0	41.5	43.0	49.0	51.0	15.5	22.5	27.0	30.0	34.0	39.0

y_3 in mhos - Replication 2

	Load - 1						Load - 2					
	T_0	T_1	T_2	T_3	T_4	T_5	T_0	T_1	T_2	T_3	T_4	T_5
O_1	57.0	55.0	60.2	61.0	83.0	103.6	39.0	47.0	49.6	51.0	56.0	55.0
O_2	20.0	18.5	17.0	22.0	26.0	26.5	21.0	20.5	25.5	28.0	30.5	33.0
O_3	32.0	33.0	37.0	40.0	39.0	45.0	43.0	54.0	56.0	61.0	70.0	78.0
O_4	12.0	11.0	19.0	17.4	18.1	17.0	31.0	40.0	48.0	63.0	59.6	71.2
O_5	52.0	50.0	58.0	62.0	72.0	73.0	39.6	40.0	44.2	43.0	45.0	46.0

y_5 in mm. Hg. - Replication 1

	Load - 1						Load - 2					
	T_0	T_1	T_2	T_3	T_4	T_5	T_0	T_1	T_2	T_3	T_4	T_5
O_1	44	42	50	46	50	32	40	55	52	45	40	37
O_2	40	36	37	41	34	36	50	55	58	45	55	55
O_3	34	40	44	40	30	36	52	50	52	50	50	48
O_4	32	39	48	41	42	34	42	40	24	34	26	22
O_5	40	36	34	36	44	46	34	34	40	40	42	42

y_5 in mm. Hg. - Replication 2

	Load - 1						Load - 2					
	T_0	T_1	T_2	T_3	T_4	T_5	T_0	T_1	T_2	T_3	T_4	T_5
O_1	36	50	42	50	46	40	32	40	44	38	40	36
O_2	58	50	50	54	44	46	30	35	30	40	46	46
O_3	34	38	48	44	46	44	30	54	54	48	38	38
O_4	38	38	40	36	36	30	30	46	28	42	32	40
O_5	28	32	42	42	40	50	36	48	54	24	38	54

y_6 in mm. Hg. - Replication 1

	Load - 1						Load - 2					
	T_0	T_1	T_2	T_3	T_4	T_5	T_0	T_1	T_2	T_3	T_4	T_5
O_1	122	118	124	126	130	110	110	115	117	120	115	112
O_2	110	108	112	115	106	112	125	130	123	120	125	125
O_3	98	104	102	102	96	102	108	114	110	110	110	108
O_4	110	114	120	113	114	110	110	110	108	112	106	100
O_5	102	98	96	94	102	98	100	100	102	102	102	102

y_6 in mm. Hg. - Replication 2

	Load - 1						Load - 2					
	T_0	T_1	T_2	T_3	T_4	T_5	T_0	T_1	T_2	T_3	T_4	T_5
O_1	106	116	108	118	114	108	106	114	114	112	114	114
O_2	122	124	118	124	116	118	100	100	102	110	120	118
O_3	98	100	104	102	104	102	98	116	112	106	100	98
O_4	100	104	104	104	110	108	96	106	98	110	108	108
O_5	98	96	106	106	110	112	100	98	92	66	78	98

y_7 in mm. Hg. - Replication 1

	Load - 1						Load - 2					
	T_0	T_1	T_2	T_3	T_4	T_5	T_0	T_1	T_2	T_3	T_4	T_5
O_1	78	76	74	80	80	78	70	60	65	75	70	75
O_2	70	72	75	74	72	76	75	75	66	75	70	70
O_3	64	64	58	62	66	66	56	64	58	60	60	60
O_4	78	75	72	72	72	76	68	70	84	78	80	78
O_5	62	62	62	58	58	52	66	66	62	62	60	60

y_7 in mm. Hg. - Replication 2

	Load - 1						Load - 2					
	T_0	T_1	T_2	T_3	T_4	T_5	T_0	T_1	T_2	T_3	T_4	T_5
O_1	70	66	66	68	68	68	74	74	70	74	74	78
O_2	64	74	68	70	72	72	70	65	72	70	74	72
O_3	64	62	56	58	58	58	68	62	58	58	62	60
O_4	62	66	64	68	74	78	66	60	70	68	76	68
O_5	70	64	64	64	70	62	64	50	38	42	40	44

y_8 in mm. - Replication 1

	Load - 1						Load - 2					
	T_0	T_1	T_2	T_3	T_4	T_5	T_0	T_1	T_2	T_3	T_4	T_5
O_1	15.8	4.8	6.5	8.4	13.0	9.8	5.9	4.2	8.0	2.3	3.2	2.2
O_2	8.1	2.3	15.2	13.3	14.7	8.0	9.2	1.0	7.0	14.1	12.8	26.5
O_3	10.5	22.0	16.6	21.4	18.6	15.8	17.2	38.5	42.7	19.0	30.8	26.0
O_4	10.1	17.6	14.7	5.6	4.9	19.2	4.8	17.1	34.3	39.2	32.2	49.4
O_5	2.3	16.8	20.6	32.4	20.6	27.2	9.1	42.9	64.0	66.5	54.0	59.0

y_8 in mm. - Replication 2

	Load - 1						Load - 2					
	T_0	T_1	T_2	T_3	T_4	T_5	T_0	T_1	T_2	T_3	T_4	T_5
O_1	1.7	3.7	1.3	3.6	2.8	4.9	2.2	3.3	6.9	8.5	6.6	7.1
O_2	10.5	12.7	16.5	17.2	18.0	27.8	10.1	22.2	12.3	30.3	32.8	41.0
O_3	4.3	9.8	7.5	10.0	5.1	6.3	4.5	35.1	21.0	15.8	17.2	14.1
O_4	11.7	14.5	14.4	22.6	16.7	14.0	10.9	48.6	67.8	102.0	82.0	92.5
O_5	2.5	6.0	1.8	11.3	28.0	14.0	1.8	12.8	13.3	8.0	15.5	14.7

PART II

Computer Data - Coded

Data	Variable	Value	Data	Variable	Value
$T^2_{....}$	y_3	13,044,910.208	$\sum_i T^2_{i..}$	y_3	14,796,321.250
	y_5	44,698.800		y_5	46,358.833
	y_6	213,785.208		y_6	219,563.250
	y_7	162,656.033		y_7	167,233.333
	y_8	7,549,080.033		y_8	9,322,040.107
$\sum_{ijk} y^2_{ijk}$	y_3	16,696,641.000	$\sum T^2_{...}$	y_3	14,105,202.125
	y_5	52,124.000		y_5	45,893.917
	y_6	226,517.000		y_6	219,100.625
	y_7	170,870.000		y_7	166,842.417
	y_8	11,696,000.000		y_8	8,384,379.250
$\sum_j T^2_{.j..}$	y_3	13,388,844.750	$\sum_{ij} T^2_{ij..}$	y_3	13,409,695.700
	y_5	45,086.300		y_5	45,305.200
	y_6	213,978.150		y_6	214,335.900
	y_7	162,786.000		y_7	162,931.200
	y_8	7,902,763.000		y_8	8,505,896.000
$\sum_{ik} T^2_{i.k}$	y_3	15,998,977.167	$\sum_k T^2_{..k.}$	y_3	13,352,457,833
	y_5	48,033.667		y_5	44,706.300
	y_6	221,768.500		y_6	214,095.617
	y_7	168,953.333		y_7	163,074 167
	y_8	10,367,547.667		y_8	7,554,360.167
$\sum_j T^2_{..}$	y_3	14,501,964.750	$\sum_i T^2_{i...}$	y_3	13,045,028.217
	y_5	47,406.000		y_5	44,714.933
	y_6	220,406.250		y_6	213,854.217
	y_7	167,622.500		y_7	162,780.067
	y_8	9,063,155.500		y_8	8,038,298.733

PART III

Sums of Squares - Coded

Source	Variable				
	y_3	y_5	y_6	y_7	y_8
SP Res.	280,168.267	3,375.483	3,154.138	1,115.417	535,761.783
L	118.008	16.133	69.008	124.033	489,218.700
O	1,060,291.917	1,195.117	5,315.417	4,186.373	835,299.217
LO	691,001.117	448.783	393.617	266.883	448,442.217
T	343,934.542	387.500	192.942	129.967	353,682.967
LT	20,732.942	202.767	288.742	21.167	113,914.300
OT	52,828.083	1,124.583	1,112.683	650.117	325,693.283
R	307,547.625	7.500	310.408	418.133	5,280.133
MP Res.	895,108.292	1,667.333	1,894.842	1,301.867	1,040,227.367
Total	3,651,730.792	7,425.200	12,731.792	8,213.967	4,146,919.967